THERMAL & FLUIDS ANALYSIS WORKSHOP

GSFC · 2015

Preliminary Thermal Design of Cryogenic Radiation Shielding

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NASA GSFC

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Introduction

- Human Space Flight beyond Earth Orbit
  - Protecting Astronauts from Galactic Cosmic Ray (GCR) and Solar Particle Events (SPEs) is critical for future human space flight beyond the earth orbit.
- Radiation shielding material
  - The conventional radiation shielding materials such as aluminum is not ideal for lengthy deep space missions. Because of the size of an aluminum nucleus, the secondary radiation produced while shielding space radiation can be just as damaging as the primary radiation and contributes to the total ionizing dose received.
  - Materials which contain smaller nuclei, such as hydrogen-rich polyethylene and liquid hydrogen, have been tested to determine their effectiveness at reducing the dose received from all sources of radiation. These shielding materials do not produce the same level of damaging secondary radiation as their heavier counterparts while providing adequate protection from primary radiation.

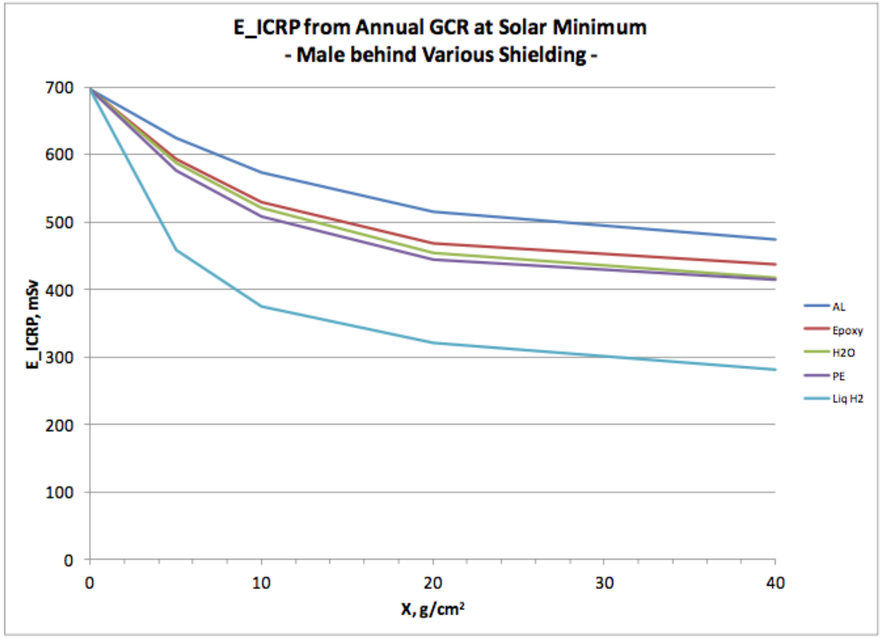
Previous Study

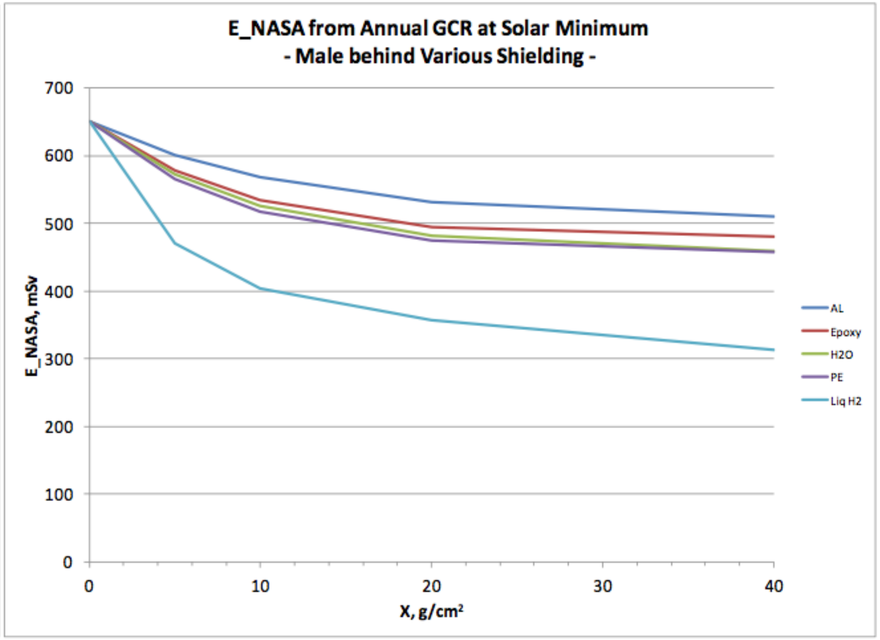
- Funded by FY 2008 NASA GSFC IRAD;
- PI: Shuvo Mustafi code 552
- Results:
  - Liquid hydrogen is the most mass effective material for protecting a spacecraft if proper design is implemented.
  - The performance of three candidate materials was studied in a LaRC study.
    - Comparing to the most commonly studied material for hydrogen shielding – hydrogen rich low density polyethylene (LDPE), the CHRS using liquid hydrogen has much lower required areal density. A 37.2 kg/m^2 areal density of liquid hydrogen would reduce the radiation exposure of astronauts to the allowable limits as dictated by a one year exposure to the background GCR and exposure to one large SPE (such as the one observed in 1972). In order to achieve equivalent performance, 86.2 kg/m^2 areal density of the LDPE shielding and 130 kg/m^2 of aluminum shielding would be needed to reduce exposure to the acceptable limits. The CHRS requires only 43% of the areal density of the LDPE shielding

Current Study

- Funded by FY 2013 NASA GSFC IRAD;
- PI: Xiaoyi Li code 552
- Goal:
  - Update radiation analysis data;
  - Trade study: compare liquid and solid hydrogen;
  - CHRS thermal design;
  - CHRS ground operation system design.

Radiation Research





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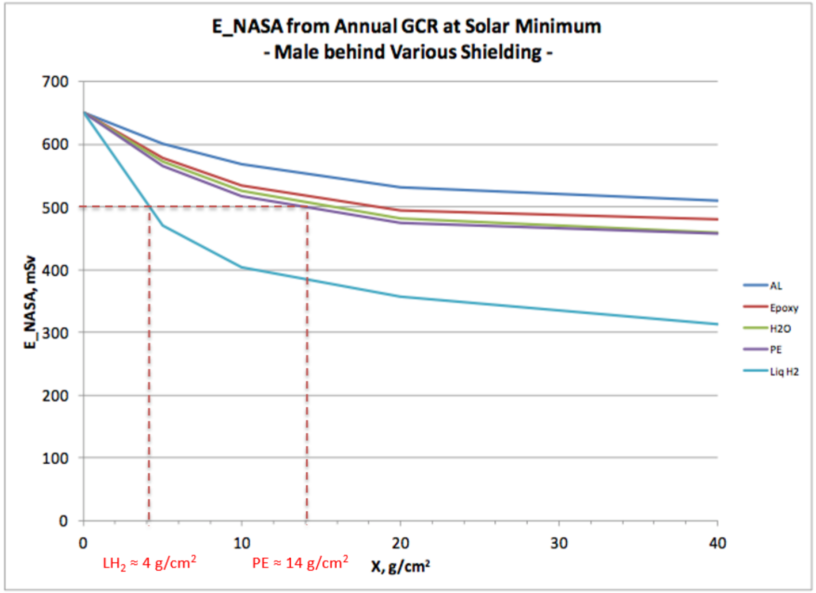
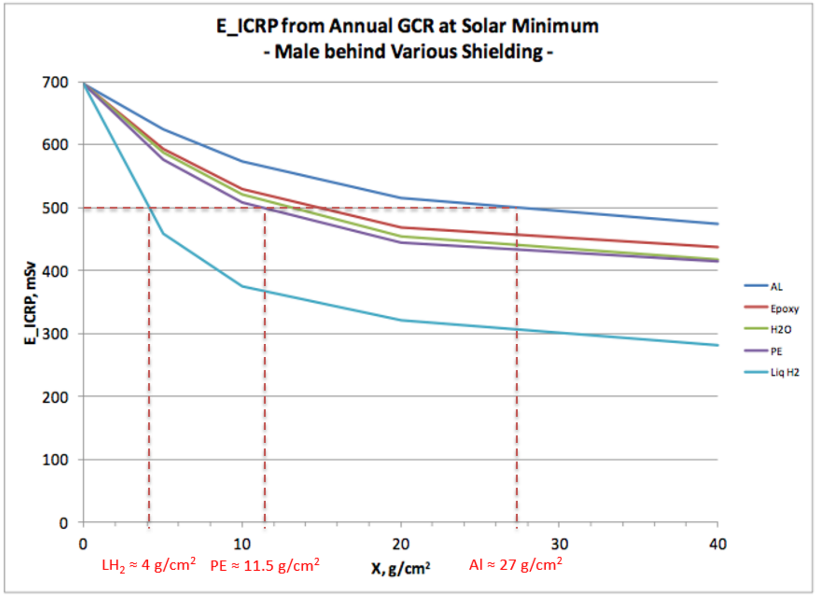
Radiation Research





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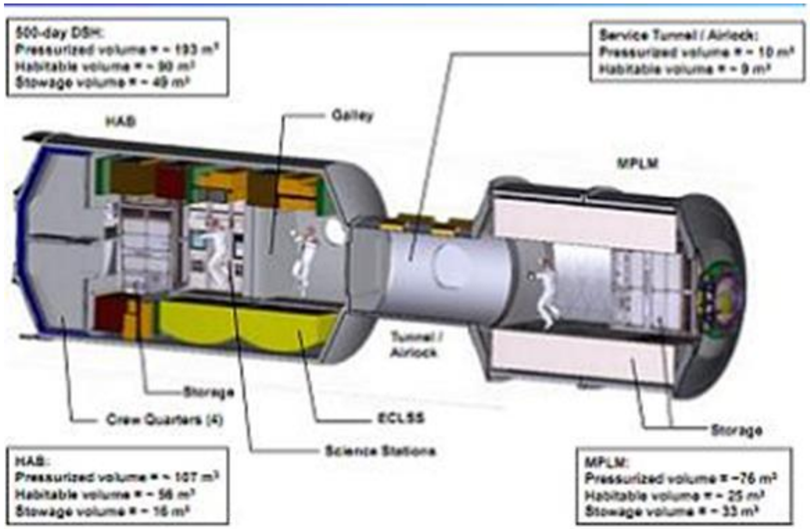
Radiation Research

- Mass Thickness Required
- LH_2: 40 kg/m^2 (without protection and tank)
- LDPE: 140 kg/m^2
- Surface Area for Crew Module: 125 m^2



Trade Study

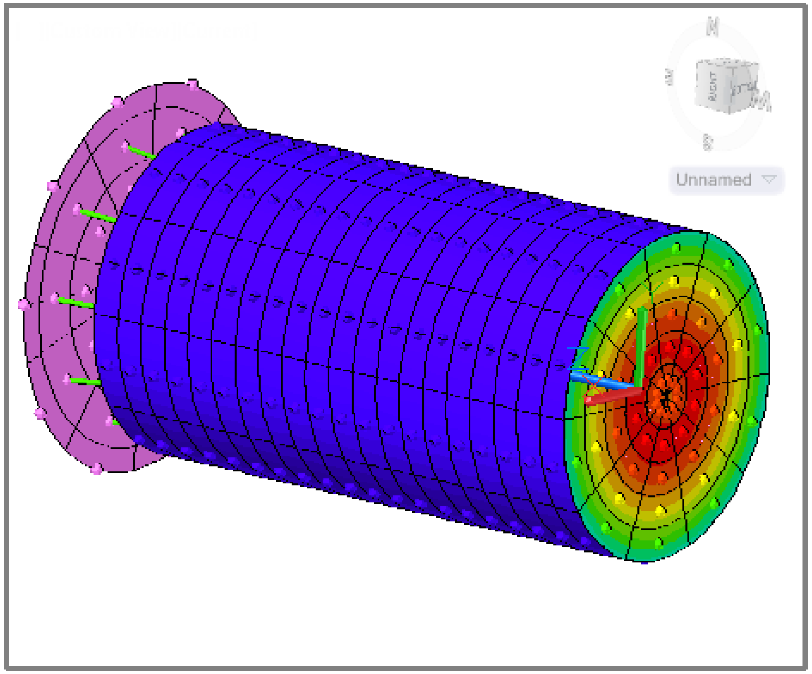
	Liquid hydrogen (Lh2)	Solid Hydrogen (Sh2)
Temperature (K)	20	<14
Slosh dynamic	Yes	No
Venting	Yes	Maybe
Time to vent	Short	Long
Temperature distribution	Local evaporation may occur	Uniform temperature distribution (with Foam)

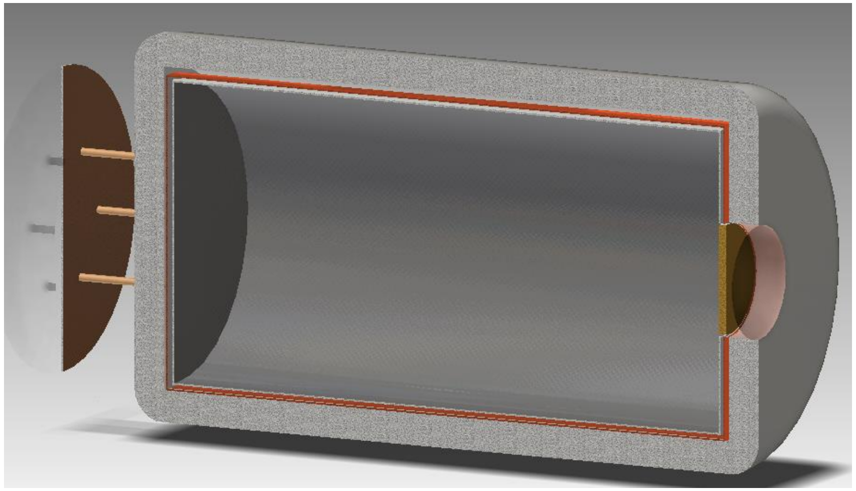
Use SH2 to extend time before venting, avoid to deal with slosh problem, and reduce or eliminate local evaporation.

Space Thermal System Requirement

- Mission length: 1- 3 years
- To maintain SH2 at below triple point
- To maintain SH2 at solid state at all shield locations
- To maintain crew module at 300K ± 5K.

Thermal Analysis

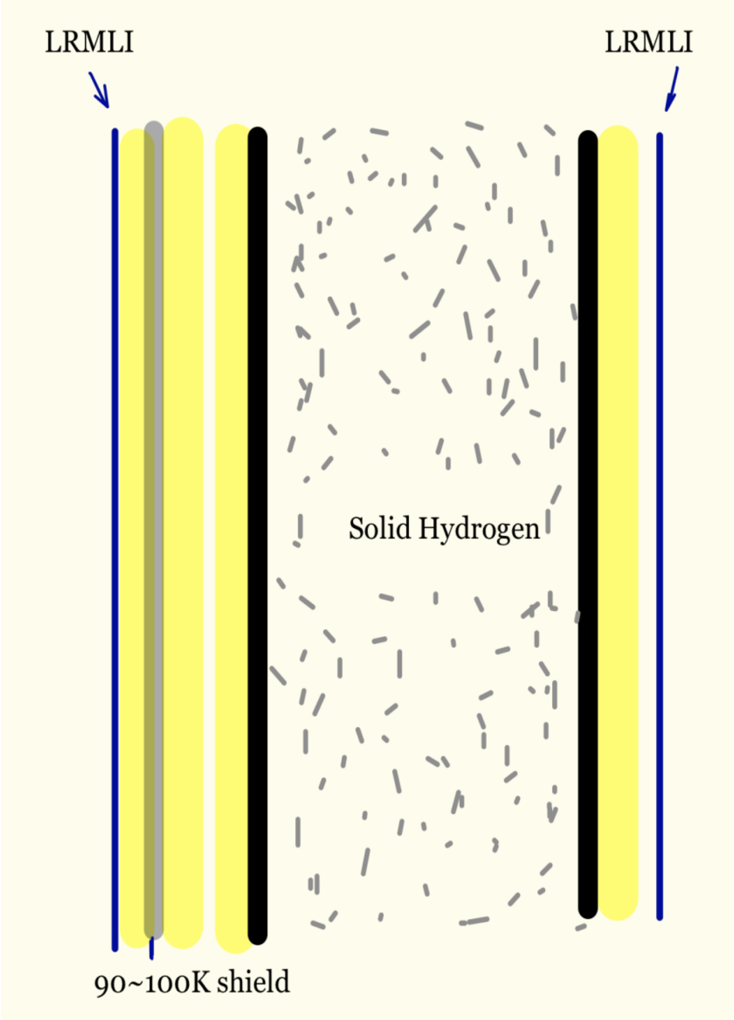




Thermal Desktop Model

Thermal Protection System

- Load Responsive MLI (LRMLI)
- MLI
- 90-100K shielding
- 90-100K Radiator
- Aluminum tank
  - Inner and outer tank wall thickness
- Aluminum foam



Results

- Mass of CHRS cryogenic thermal system/surface area
  - 30kg/m^2
- Heat leak at Low Earth Orbit (LEO)
  - 130Watts
- Heat leak at Mars Orbit
  - 69 Watts
- Heat leak at deep space
  - Less than 1Watt
- Heater sizing
  - Less than 50 Watts to maintain the crew module at room temperature

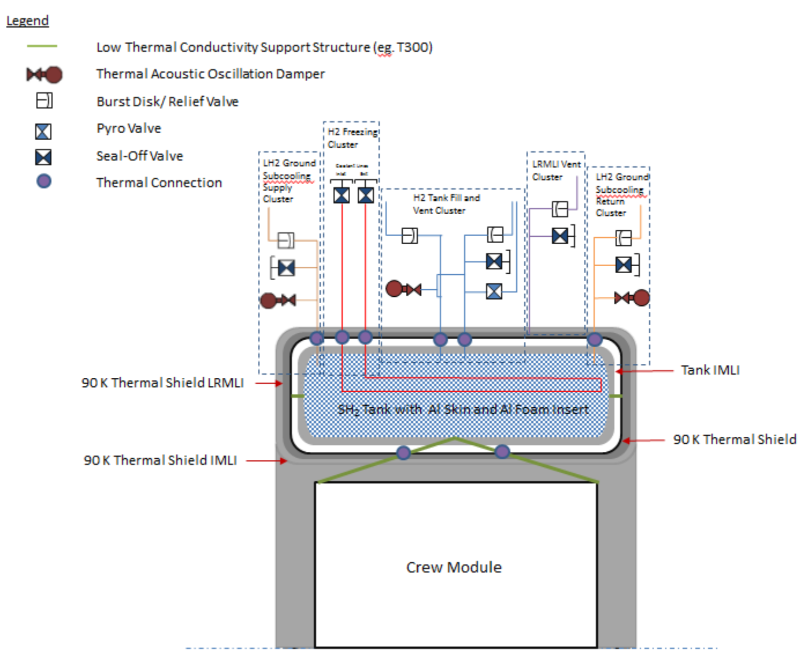
Ground Thermal System Requirements

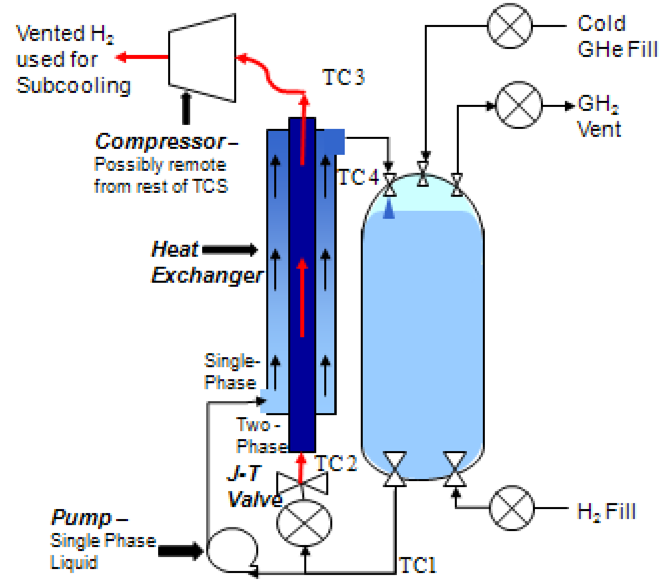
- To lower liquid hydrogen temperature close to triple point with subcooler
- To freeze liquid hydrogen with cryocoolers and liquid hydrogen
- To lower solid hydrogen temperature to 10 K with cryocoolers and liquid hydrogen
- To prevent hydrogen evaporation with LRMLI
- To maintain solid hydrogen state during launch

Ground Thermal System Design

- CHRS Ground System Schematic

Subcooler system





Cryocooler

- Use cryocooler for longer duration mission more than 3 years.
- Creare is developing 20K/20W cryocooler for CPST program.
- Current 20K/20W cryocooler provides few watts cooling at 14K.
- The power input is less than 1400W, and mass is around 66kg.
- Mass added to the system is less than 1kg/m^2.

Conclusion

- Solid hydrogen can be used for radiation shielding for human spaceflight.
- The CHRS shielding with thermal protection system weighs 70kg/m^2.
- With CHRS, the mass of crew module with radiation shielding reduces from more than 26,500 kg with LDPE to less than 17,800 kg. CHRS saves nearly 8,800 kg for a 4m diameter and 8 m long cylindrical crew module and halves the required shielding mass when compared with polyethylene shields, and close to 44 million dollars in launch cost, based on $ 5000 /kg estimate from SpaceX.
- With a cryocooler, the system can apply to missions of any lengths.

Future Work

- Researchers have been doing tests with hydrogen rich materials.
- There is no liquid/solid hydrogen radiation testing for human spaceflight.